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Flexural Toughness of Steel Fiber Reinforced Concrete

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ABSTRACT. Steel fiber reinforced concrete (S.F.R.C.) is distinguished from plain concrete by its ability to absorb large amount of energy and to withstand large deformations prior to failure. The preceeding characteristics are referred to as toughness. Flexural toughness can be measured by taking the useful area under the load-deflection curve in flexure.

Detailed experimental investigation was carried out to determine flexural toughness and toughness indices of S.F.R.C. The variables used in the investigation were: maximum aggregate size, water/cement ratio, fine/coarse aggregate ratio, steel fiber percentage by volume, and steel fiber type.

The aim of this paper is to present the findings of the investigation and equations obtained for predicting the desired flexural toughness and in turn the toughness indices for S.F.R.C. These equations are dependent on the ultimate flexural strength, first crack multiple deflections, and concrete specimen size. They are independent of the concrete matrix composition.

1. Introduction

The addition of steel fibers to concrete not only results in a large increase in flexural strength, but also a considerable increase in toughness. After cracking, the cracks can not extend without stretching and debonding of the fibers. As a result, a large additional energy is absorbed before complete separation of the specimen occurs. Toughness can be measured in various ways. Static, impact, and fatigue tests have been used. Static loading test is preferred because the variability of the results is lower and the equipments needed to perform the test is usually available. Most of the application of steel fiber reinforced concrete (S.F.R.C.) has been in the field of pavements and shotcrete linings and thus the behaviour in flexure is accepted as being the most important. Flexural toughness can be measured in terms of the total area under load-deflection curve in flexure[1]. This is an extreme, because by the time the load reaches zero, S.F.R.C. would have far exceeded its serviceability in terms of cracks and deflection. The other extreme is the use of the area under load-deflection curve up to first crack load. This area represents only the energy absorbed up to the point where the fibers start to contribute to the load capacity. An intermediate area is thought to be more appropriate to reflect the beneficial effect of fibers without hindering the serviceability requirements. Precise definition of this area has not been settled yet. The ASTM standard test method C-1018[2] recognizes this fact explicitly under article 9.6. Johnston[3] proposed the use of the area under load-deflection curve up to the maximum load as a base for determining flexural toughness. Besides the unsuitability of this approach for fibers producing multiple peaks on the curve, it greatly limits the advantages gained by the addition of fibers. Henager[4] proposed a toughness index as a measure of the energy absorption capability of fiber reinforced concrete. He defined this toughness index as the area under load-deflection curve up to a 0.075 in. center-deflection divided by the first crack area. This definition was originally adopted by the ACI Committee 544 for calculating toughness area and toughness index[5]. Henager and the senior author[4,6] investigated separately the use of the area under load-deflection curve to the point following the maximum load where the load is 0.80 of the maximum. The toughness index calculated based on the 80% of the maximum load showed inconsistent results when different mixes were used. Zollo[7] took a closer look at flexural testing procedures. He ran flexural tests with varying span to depth ratio, fiber shape, and matrix type. The results showed that the toughness suggested by ACI Committee 544 is not a viable measure of the material system performance. Johnston[8] presented an approach to assess and define the flexural toughness of fiber reinforced concrete. It comprises a series of indices based on material behavior up to specified multiples of the first crack deflection. The essence of this approach was later adopted by ASTM as the basis for presenting the standard test method (ASTM C-1018)[2]. The testing method requires that the length of the test specimen shall be at least 2 in. greater than three times the depth tested in flexure under third-point loading arrangements. Ward and Li[9] studied the dependence of flexural behavior of fiber reinforced mortar on material fracture resistance and beam size. They investigated the possibility of characterizing the tensile fracture properties of mortar using only the flexural and first crack splitting tensile strength and presented three new flexural toughness indices. Nanni[10] studied the load deformation response of fiber reinforced concrete (F.R.C.) subjected to flexural and split tensile tests. He concluded that split tension test can not substitute for the standard flexural test in determining the post cracking performance of F.R.C. Studies have shown that the primary factors, influencing toughness are the type, volume percentage, aspect ratio, nature of deformation, and orientation of the fiber in concrete itself – the same parameters which influence the maximum load[8].

A detailed experimental investigation was carried out to determine flexural toughness and toughness indices of S.F.R.C. The aim of this paper is to present the outcome of the investigation and the equations obtained for predicting the flexural toughness and in turn the toughness indices of S.F.R.C.

2. Research Significance

The principal objectives of the research presented here were :

a. To study the effect of fiber and mix parameters simultaneously on flexural toughness and toughness indices.

b. To prove that the behaviour of S.F.R.C. (up to a certain deformation) closely resembles that of an elasto-plastic material.

c. To find equations for predicting toughness and toughness indices.

It is significant to present the equations obtained for predicting the desired toughness areas and in turn the desired toughness indices. These equations provide continuous scale for toughness areas and toughness indices predictions for use with different serviceability requirements as those suggested in article (9.6) of ASTM (C-1018)[2]. The equations are dependent on the ultimate flexural strength, first crack multiple deflection, and concrete specimen size. They are independent of the concrete matrix composition. It is also significant to show that S.F.R.C. characteristic behaviour was proven to be analogous to that of elasto-plastic material. In addition, this research provides important data which is needed in the field of understanding S.F.R.C. properties.

3. Experimental Program

Table 1 shows the plain and S.F.R.C. mix design variables. They can be summarized as follows:

1. Round gravel maximum size (*MSA*).
   a) 1″   b) ½″   c) ¼″
2. Percentage fine aggregate by weight (% *FA*).
   a) 35%   b) 55%   c) 75%
3. Water-cement ratio (*W/C*).
   a) 0.42   b) 0.51   c) 0.60
4. Fiber concentration by volume (V_f).
   a) 0.00%   b) 0.75%   c) 1.50%
5. Fiber type.
6. Brass-coated steel fiber with a round cross-sectional area (0.016 × 1″, ℓ/d = 63).
7. Brass-coated deformed steel fiber (0.010 × 1, ℓ/d = 100)

To achieve the goals of this study 27 plain concrete mixes (3 *MSA* × 3% *FA* × 3 *W/C*) and 108 S.F.R.C. mixes (3 *MSA* × 3 *FA* × 3 *W/C* × 2 V_f × 2 fiber type) for a total of 135 mixes were made. From the results of a preliminary study, 650 lbs/cu yd type

TABLE 1. Plain and steel fiber reinforced concrete mix design variables.

		Plain concrete			Straight fibers (0.016 × 1")						Deformed fibers (0.01 × 1")					
					$V_f = 0.75\%$			$V_f = 1.50\%$			$V_f = 0.75\%$			$V_f = 1.50\%$		
		w/c			*w/c*						*w/c*					
MSA	% *FA*	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60	0.42	0.51	0.60
1"	35	–	–	–	×	–	–	–	–	–	×	–	–	–	×	–
	55	–	–	–	–	–	–	–	–	×	–	–	–	–	–	–
	75	–	–	–	×	–	–	–	–	–	–	×	×	–	–	–
½"	35	–	–	–	×	–	×	–	–	–	–	–	–	–	–	–
	55	–	–	–	–	×	–	–	–	–	–	–	–	–	×	×
	75	–	–	–	–	–	–	–	–	×	–	–	–	–	–	–
¼"	35	–	–	×	–	–	×	–	–	–	–	–	×	–	–	–
	55	–	–	–	–	–	×	–	–	–	–	–	×	–	–	–
	75	–	–	–	–	–	–	×	–	–	–	–	×	–	–	–

(×) = 4 flexural specimens.
(–) = 2 flexural specimens.

I cement was found to be adequate and hence was chosen for all mixes in this study. The flexural specimen dimensions were 4 × 4 × 14 in.

Four flexural specimens were cast from each of the first twenty randomly chosen batches for a total of 80 beams. This was done to establish the extent of variations in first crack load, ultimate flexural strength. Two flexural specimens were cast from each of the remaining 115 mixes. A total of 310 flexural beams were made. External vibration was used for making all flexural specimens. All specimens were immersed in saturated lime water and the curing temperature was kept at 73.4 + 3°F from the time of the molding until testing time at twenty-eight days.

4. Flexural Toughness

The approach for determining flexural toughness of S.F.R.C. is based on the assumption that the load-deflection curves (similar to that shown in Fig. 1) for beams made of steel fiber reinforced concrete closely resemble that of a beam made of an elasto-plastic material, assuming the yield and ultimate moment capacities of the elasto-plastic beam are equal. Figure 2 shows the essence of that approach.

Two different areas under the third-point flexural load versus deformation diagrams were calculated. The first was based on first crack deflection and first crack areas of plain concrete beams. The second was based on first crack deflection and first crack areas of S.F.R.C. beams. This was done because of the toughness index definitions. Toughness indices were defined as the amount of energy required to deflect a fiber reinforced beam used in the modulus of rupture tests a given value compared to the energy required to bring :

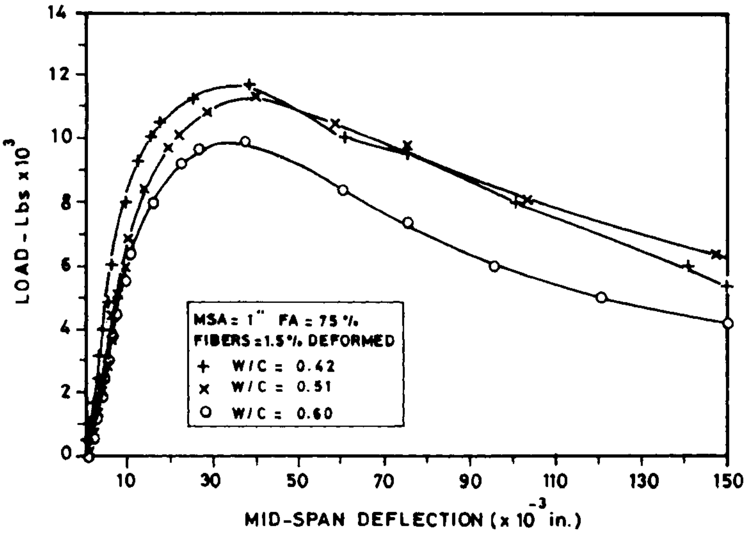

FIG. 1. Load-deflection diagram.

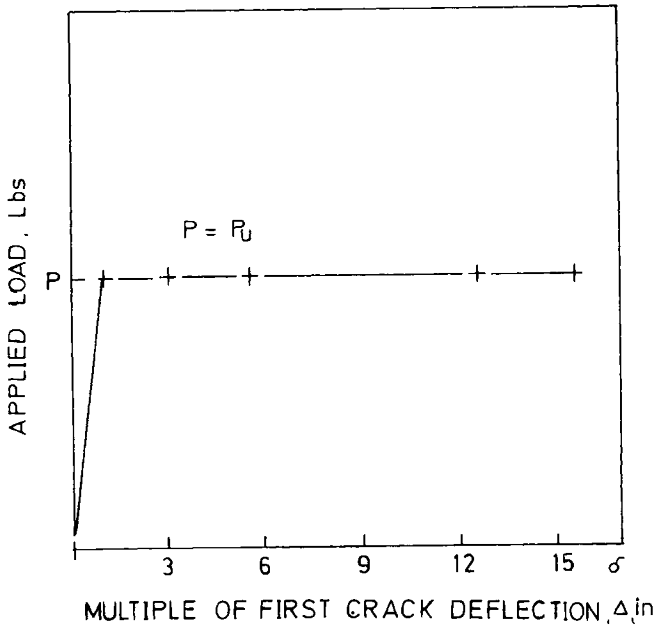

FIG. 2. Elasto-plastic material load-deflection diagram.

a) Comparable plain concrete beam to the point of first crack.
b) A fiber reinforced beam to the point of first crack.

The improvement in toughness index of S.F.R.C. over that of plain concrete dictated a comparison between the energy under load-deflection diagram of S.F.R.C. with that obtained for plain concrete. To avoid casting separate plain concrete beams, it was suggested[3,6,7] to use the first crack area of S.F.R.C. for calculating the toughness index. In this study, the toughness indices based on plain and S.F.R.C. first crack areas were investigated to see if they can be used interchangeably. Load deflection diagrams were plotted for all the specimens tested. The first crack loads were taken as the value of the loads when the load deflection diagrams starts to deviate from linearity as defined by the ACI Committee 544[4]. Based on this, the first crack load and first crack area were determined for both plain and S.F.R.C. beams.

The author[6] studied the influence of concrete matrix components on flexural toughness. The amount of energy expended to extend a crack expressed as the area under load deflection diagram depends on ultimate load, first crack load and deflection, Fig. 1. In addition, fine aggregate content, water-cement ratio, and fiber distribution in the mix greatly affect the amount of energy required to extend a crack by producing S.F.R.C. which has higher first and ultimate cracking loads, Fig. 3 and 4.

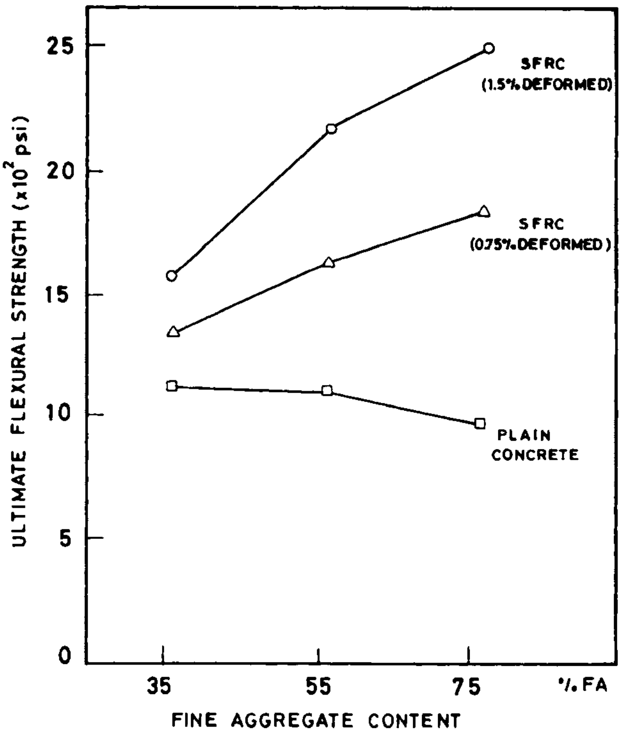

FIG. 3. Ultimate flexural strength vs fine aggregate content.

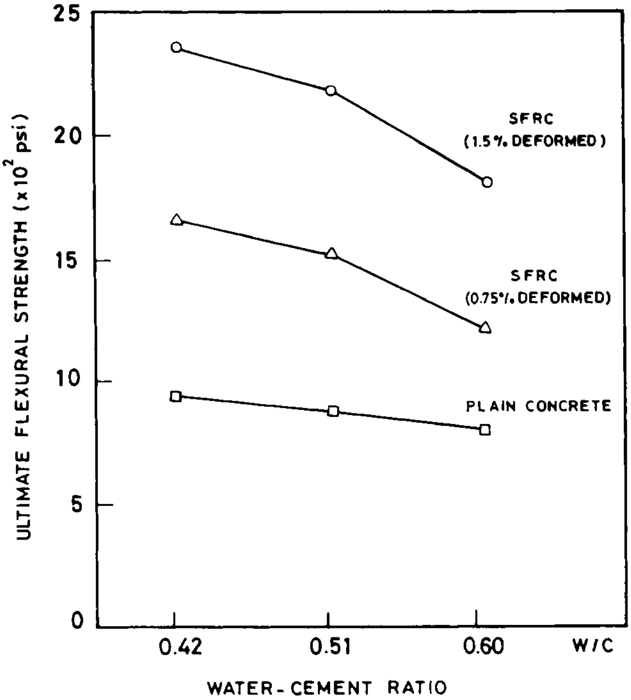

FIG. 4. Ultimate flexural strength vs water-cement ratio.

The largest area were observed for concrete reinforced with 1.5% deformed steel fibers ($\ell/d = 100$), having high fine aggregate content, and low water-cement ratio. The high fine aggregate content provided the media for better fiber distribution and the low water-cement ratio produced high interfacial bond strength and thus large amount of energy was needed to extend the crack during the fiber pull out process.

The overall average first crack deflections of plain and S.F.R.C. investigated in this study were 0.0060 and 0.0064 in., respectively. The usual range suggested in article 9.5 of ASTM (C – 1018) is 0.0040 to 0.0060. Using the overall average first crack deflections, the 0.075 in. central deflections can be approximated to 12.5 times the first crack deflections.

4.1 Analysis of Flexural Toughness

Flexural toughness data were analyzed based on the assumption that S.F.R.C. load-deflection diagrams are similar to those of elasto-plastic materials. To prove that, toughness areas and toughness indices based on energies measured up to first crack point and energies measured to several chosen multiplies of first crack deflection were compared with those calculated values for elasto-plastic materials. The toughness indices based on plain concrete first crack deflections and first crack areas were higher than those based on S.F.R.C. first crack deflections and first crack areas. The first crack load defined as the load level at which load deflection diagram deviates from linearity can be misleading since in the case of high fiber content the presence of fibers causes the crack to extend very slowly and thus forced the load deflection diagram to maintain linearity beyond the actual first cracking load. Accordingly, the first crack areas of S.F.R.C. were larger than those of plain concrete due to the influence of fibers in increasing the first crack loads and first crack deflection. The average increase in first crack loads of S.F.R.C. to those of plain concrete were 3, 11, 8 and 20 percent for using 0.75%, 1.50% by volume of straight and deformed fibers respectively[6]. Similar results were given by Snyder and Lankard[11], ACI Commitee 544[1] and Mangat[12].

The toughness index ratios for S.F.R.C. (I_1, I_2, I_3) given in Tables 2 and 3 ranged from 2.5 to 2.9, 4.9 to 6.5, and 1.9 to 2.2 compared to 3.0, 6.0 and 2.0 for elasto-plastic material. Comparing those values, the analogy of the two materials behavior can be clearly observed.

4.2 Prediction of Toughness and Toughness for S.F.R.C.

The similarity between S.F.R.C. and elasto-plastic materials load deflection curves has been established in the previous section. The following is a brief derivation of the basic equation for predicting toughness areas for S.F.R.C.

The area up to first crack $= \dfrac{P\,\delta}{2}$

where

δ = First crack deflection, in.

TABLE 2. Comparisons between steel fiber reinforced concrete flexural toughness index ratios and elasto-plastic material index ratios.

	Based on first crack area of plain concrete				Based on first crack area of steel fiber reinforced concrete				Elastic-plastic material
	Straight fibers		Deformed fibers		Straight fibers		Deformed fibers		
	0.75%	1.50%	0.75%	1.50	0.75%	1.50%	0.75%	1.50%	
$I_1 = T.I._{(15.5\delta)} / T.I._{(5.5\delta)}$	2.6	2.8	2.9	2.9	2.5	2.7	2.7	2.6	3
$I_2 = T.I._{(15.5\delta)}) / T.I._{(3\delta)})$	5.0	5.9	6.2	6.5	4.9	5.7	5.7	5.7	6
$I_3 = T.I._{(5.5\delta)} / T.I._{(3\delta)}$	1.9	2.1	2.1	2.2	1.9	2.1	2.1	2.1	2
No. of specimens	124	116	122	116	68	60	66	60	

δ = First crack deflection.
$T.I.$ = Toughness index.

TABLE 3. Comparisons between steel fiber reinforced concrete flexural toughness index ratios and elasto-plastic material index ratios.

	Flexural toughness index ratios for :						
	Both fiber type based on plain concrete δ	Both fibers based on S.F.R.C. δ	Straight fibers based on plain concrete δ	Deformed fibers based on plain concrete δ	Straight fibers based on S.F.R.C. δ	Deformed fibers based on S.F.R.C. δ	Elastic plastic material
$I_1 = T.I._{(15.5\delta)}/T.I._{(5.5\delta)}$	2.6	2.8	2.7	2.9	2.6	2.7	3
$I_2 = T.I._{(15.5\delta)}/T.I._{(3\delta)}$	5.5	5.9	5.5	6.4	5.30	5.7	6
$I_3 = T.I._{(5.5\delta)}/T.I._{(3\delta)}$	2.1	2.1	2.0	2.2	2.0	2.1	2
No. of specimens	310	254	184	182	128	126	

δ = First crack deflection.
$T.I.$ = Toughness index.

P = Applied load at first crack, lbs.

The area up to any chosen multiple of the first crack deflection (Fig. 2)

$$A = \frac{P\,\delta}{2} + (\Delta - \sigma)\,P_u \qquad \text{in.} - \text{lb.} \tag{1}$$

where

Δ = Any chosen multiple of first crack deflection, in.

P_u Ultimate applied load, lbs.

For a third-point loading on 4 × 4 × 14 in. flexure beams having a clear span of 12 in.

$$\sigma_{cu} = \frac{P_u\,L}{bh^2} = \frac{3\,P_u}{16} \tag{2}$$

where

σ_{cu} = Ultimate flexure stress, psi.

Since flexural toughness and ultimate flexural strength are influenced by the same parameters[1,7], normalizing the effect of these parameters is done by taking the area up to any chosen multiple first crack deflection (toughness) as a percentage of the ultimate flexural strength of S.F.R.C. as follows :

$$R = \frac{A}{\sigma_{cu}} \times 100 \text{ in.}^3 \tag{3}$$

$$R = \frac{\frac{P\,\delta}{2} + (\Delta - \delta)\,P_u}{\frac{3\,P_u}{16}} \times 100 \tag{4}$$

The contribution of the term $P\,\delta/2$, representing the first crack area, to the total area is rather small and so assuming that $P = P_u$ will not practically effect the computed values of R. Taking this fact and replacing P with P_u, Equation 3 can now be simplified as

$$R = \frac{8}{3}\,(2\Delta - \delta) \times 100 \text{ in.}^3 \tag{5}$$

The areas under load-deflection diagrams of S.F.R.C. taken as percentage of the ultimate flexural strength were calculated for multiple first crack deflection $\delta = 1, 3, 5.5$, and 15.5. These calculations were based on first crack deflections of plain and S.F.R.C. In addition, the areas up to 0.075 in. central deflection (approximately 12.5 times first crack deflection) and the areas up to 80 percent of the maximum load expressed as percentages of the ultimate load were also determined. The effect of the area up to first crack deflection as a percentage of the ultimate flexural strength on the other percentage values diminishes with increasing the chosen value of multiple first crack deflection. The results of those calculations are summarized in Tables 4 and 5. Using the areas as percentages of the ultimate flexural strength in combination with the multiple first crack deflection values used in their calculations, several regression equations were obtained to predict the desired toughness areas for S.F.R.C.

TABLE 4. Summary of average areas under P - δ diagrams as % of σ_{cu}.

Areas up to multiple crack deflections of	Straight and deformed fibers based on plain concrete	Straight and deformed fibers based on fibrous concrete δ	Straight fibers based on plain concrete δ	Deformed fibers based on plain concrete δ	Straight fibers based on fibrous concrete δ	Deformed fibers based on fibrous concrete δ
$1 \times \delta$	1.39	1.14	1.26	1.00	1.44	1.35
$3 \times \delta$	7.71	6.75	7.10	6.40	7.55	7.87
$5.5 \times \delta$	15.73	14.12	14.29	13.94	15.06	16.41
$12.5 \times \delta$	33.02	32.87	32.29	33.45	32.44	33.60
$15.5 \times \delta$	41.08	39.17	38.35	39.98	39.06	43.11
Areas up to 80% P_u	29.45	29.17	26.78	31.55	27.00	31.89
No. of specimens	310	254	184	182	128	126

δ = First crack deflection.
σ_{cu} = Ultimate composite flexural strength, psi.

1. For straight steel fibers (0.016 × 1″) reinforced concrete based on first crack deflections of comparable plain concrete.

$$R = 2.57\,\Delta - 0.61 \qquad \text{(Fig. 5)} \qquad (6)$$

where

R = Area under flexural load-deflection diagram taken as a percentage of the ultimate flexural strength.

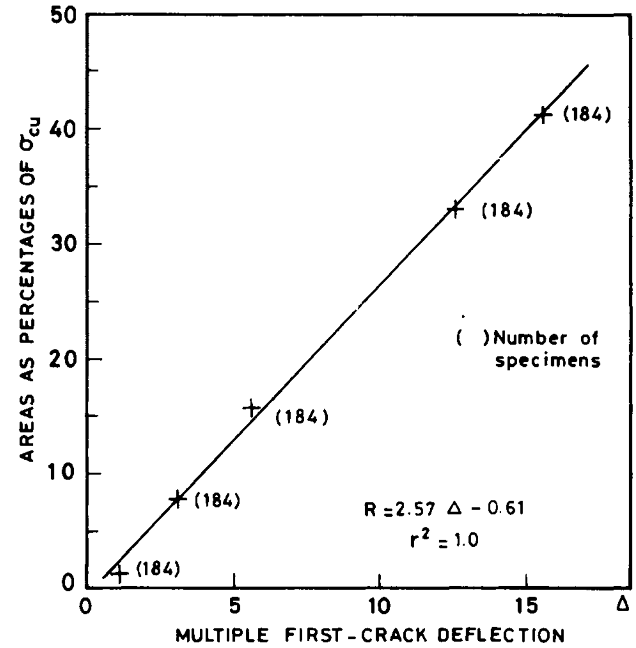

FIG. 5. Areas as percentages of σ_{cu}, vs multiple first crack deflection (straight fibers based on plain concrete first crack deflections).

2. For straight steel fibers (0.016 × 1″) reinforced concrete based on first crack deflections of S.F.R.C.,

$$R = 2.58\,\Delta - 0.24 \qquad \text{(Fig. 6)} \qquad (7)$$

3. For deformed steel fibers reinforced concrete (0.01 × 1″) based on first crack deflections of comparable plain concrete beams,

$$R = 2.73\,\Delta - 1.49 \qquad \text{(Fig. 7)} \qquad (8)$$

4. For deformed steel fiber reinforced concrete (0.01 × 1″) based on first crack deflections of S.F.R.C.,

$$R = 2.80\,\Delta - 0.55 \qquad \text{(Fig. 8)} \qquad (9)$$

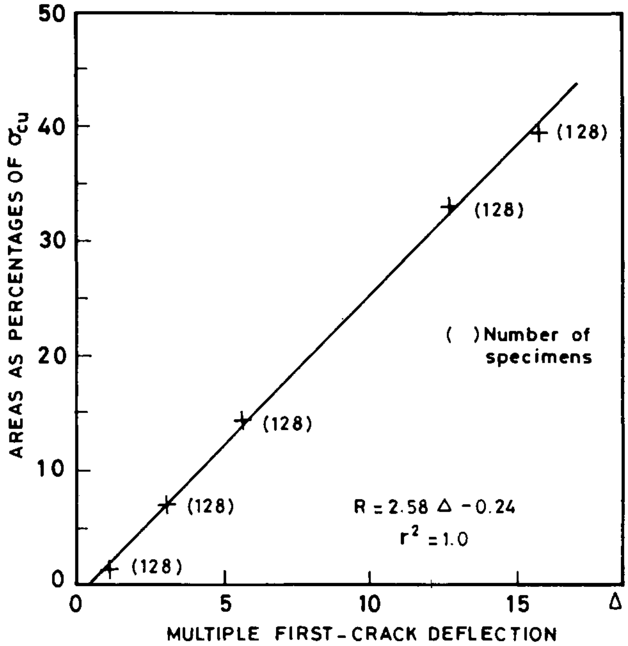

FIG. 6. Areas of percentages of σ_{cu} vs multiple first crack deflection (straight fibers) based on S.F.R.C. first crack deflections.

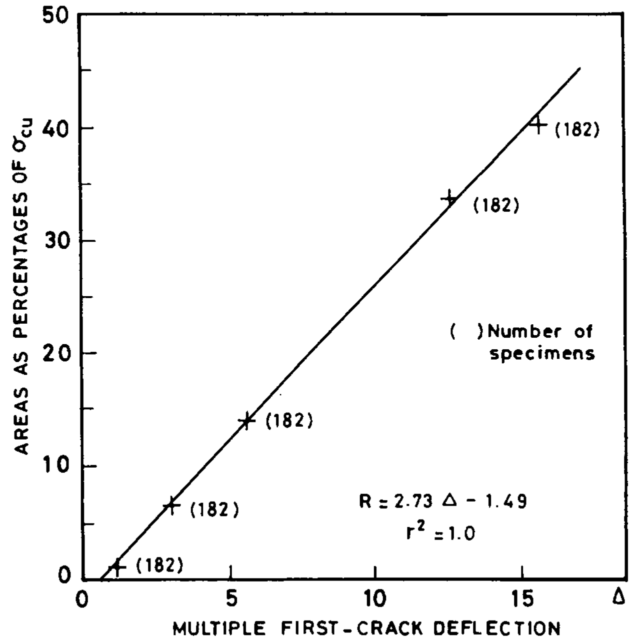

FIG. 7. Areas of percentages of σ_{cu} vs multiple first crack deflection (deformed fibers based on plain concrete first crack deflections).

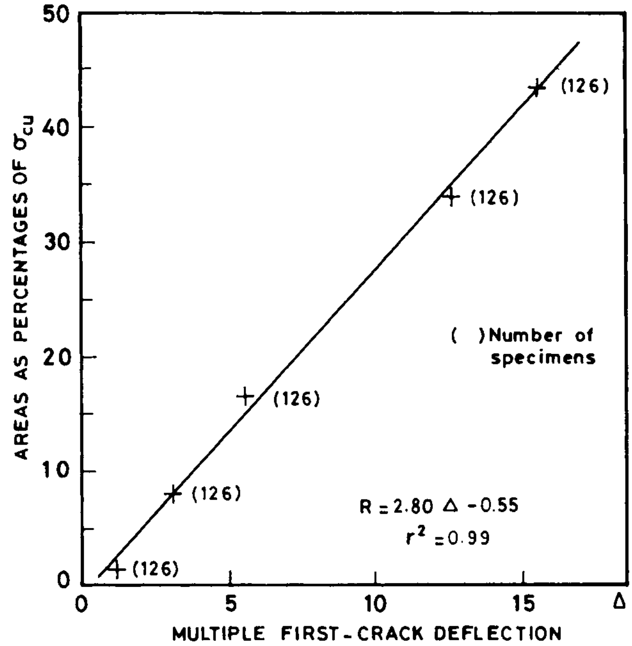

FIG. 8. Areas of percentages of σ_{cu} vs multiple first crack deflection (deformed fibers based on S.F.R.C. first crack deflections).

5. A general equation for both steel fibers types used in this study based on first crack deflections of comparable plain concrete beams,

$$R = 2.65\,\Delta - 1.05 \qquad \text{(Fig. 9)} \tag{10}$$

6. A general equation for both fiber types based on first crack deflections of S.F.R.C.,

$$R = 2.69\,\Delta - 0.40 \qquad \text{(Fig. 10)} \tag{11}$$

If the average first crack deflection obtained for all concretes investigated in the study was used in Eq. 5, the following can be calculated :

Using $\delta = 0.006$ in.

$$\Delta = 12.5\,\delta$$

$$R = \frac{8}{3}\,(25\,\delta - \delta) \times 100 = 38.4\%$$

The 38.4 percent is the actual percentage for perfect elasto-plastic material. The calculated percentage for S.F.R.C. using Equation 11 was 33 percent. Similar values can be obtained using Equations 6 to 10.

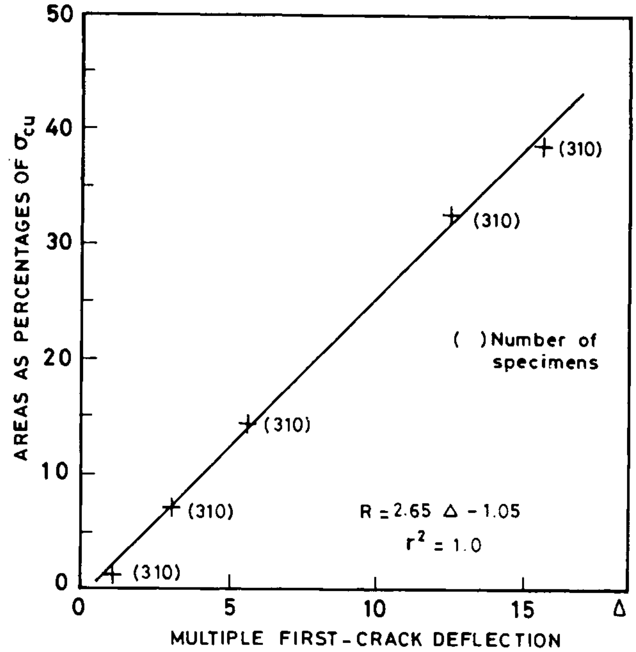

FIG. 9. Areas of percentages of σ_{cu} vs multiple first crack deflection (straight and deformed fibers based on plain concrete first crack deflections).

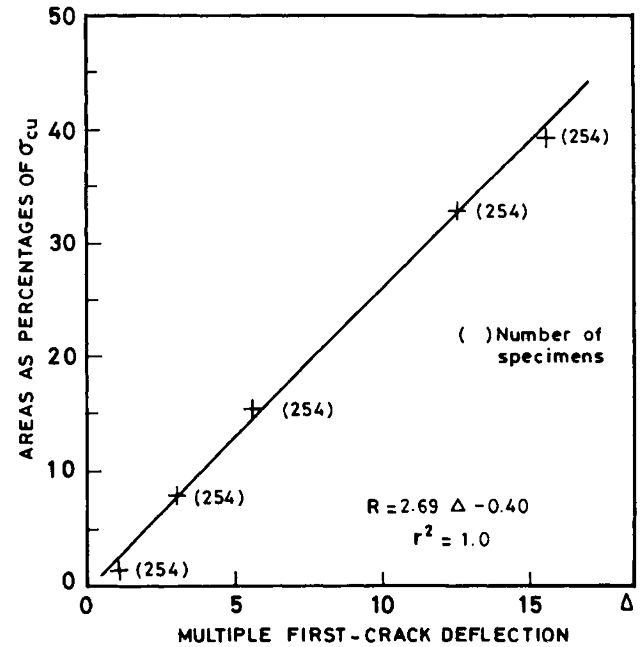

FIG. 10. Areas of percentages of σ_{cu} vs multiple first crack deflection (straight and deformed fibers based on S.F.R.C. first crack deflections).

Figures 5 to 10 show the average data points used in the derivation of Equations 6 to 11 and the straight line fitted to them. Equations 6 to 11 are independent of the plain concrete composition and are dependent on the ultimate flexural strength, first crack multiple deflections, and the concrete specimen size dimension[6].

Equations 6 to 11 can be used for S.F.R.C. toughness area predictions as follows :

a) Obtain first crack load, ultimate load, the first crack deflection based on the ACI Committee 544[5] and calculate the ultimate flexural strength (psi) and the first crack area (in. – lb),

b) Choose the desired multiple first crack deflection for the serviceability required and substitute in Equations 6 to 11 or enter figures to obtain the ratio R (in^3),

c) Multiply the ultimate flexural strength by the ratio R to obtain the toughness area (in. – lb),

d) Divide the toughness area by the first crack area to get toughness index.

First crack load and ultimate flexural strength can be alternatively predicted from equations based on the law of mixture approach for the fiber under consideration.

Equations 6 to 11 are not suitable to predict the first crack area with great accuracy because of the followings :

a) First crack areas and first crack deflections for plain concrete depend on the concrete mix composition.

b) S.F.R.C. first crack areas have larger variations than those of plain concrete because of the presence of fibers in the mix. First crack areas of S.F.R.C. are dependent on the fiber type, content and distribution in the mix.

For the above reasons, and because of the high sensitivity of the flexural toughness index to first crack areas, flexural tests should be conducted until ultimate load values are reached.

The use of 80 percent of the maximum load to predict the flexural toughness of S.F.R.C. showed a very high scatter and little consistency with either the concrete strength or the fiber concentration in the mix. It either overstated or understated the toughness index values depending on the load-deflection curve characteristics. The average toughness areas calculated based on 80 percent of the maximum load are presented in Tables 4 and 5. Full details are given in Reference [6].

5. Conclusions

For flexural toughness obtained using flexural tests under third point loading arrangements, the following can be concluded :

1. The amount of energy expressed as the area under flexural load-deflection diagram depended on fine aggregate content, water-cement ratio, fiber type, and fiber content.

2. Steel fiber reinforced concrete load-deflection diagram characteristics presented as toughness index ratios resemble those observed for elasto-plastic materials.

3. Several linear equations were obtained to predict the desired flexural toughness for S.F.R.C. as a percentage of ultimate flexural strength. Those equations are reliable and are dependent on the ultimate flexural strength, first crack multiple deflections, and concrete specimen size. They are independent of the concrete matrix composition.

4. Flexural toughness areas and toughness indices can be predicted without having to compute the total area under flexural load-deflection diagram. Continuous assessment of toughness is possible depending on material performance in the field.

5. The equations predicted a higher toughness for concrete reinforced with deformed steel fibers with a high aspect ratio ($\ell/d = 100$) than those predicted for concrete made with straight steel fibers ($\ell/d = 63$).

6. Using area values under flexural load-deflection diagrams, based either on multiple first crack deflections of plain concrete or S.F.R.C., did not practically effect the prediction equations for both fibers used in this study.

7. Because of the high variations in first crack areas for both plain and S.F.R.C. and the sensitivity of toughness index to those areas, Equations 4 to 11 cannot be used to predict the first crack areas with high accuracy (they are more suited for areas beyond the first crack).

8. The use of areas up to 80 percent of the maximum flexural loads to obtain flexural toughness showed no consistency with either the concrete strength or the fiber concentration in the mix.

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متانـــة الخرسانـــة المسلحـــة بالأليـــاف المعـــدنية

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**قسم الهندسة المدنية ، كلية الهندسة ، جامعة ميتشجان ، آن آربـــر - الولايات المتحدة الأمريكية

المستخلص . تختلف الخرسانة المسلحة بالألياف المعدنية عن الخرسانة العادية بقدرتها على امتصاص كمية كبيرة من الطاقة وتحملها لتشوه أكبر عند الانهيار . تسمى هذه الخاصية بالمتانة . ويمكن قياس المتانة بحساب المساحة المفيدة تحت منحنى الحمل والانحناء .

لقد تم القيام بدراسة مفصلة لحساب المتانة الالتوائية ، وبالتالى معاملات المتانة ، وكانت متغيرات الدراسة هى : المقاس الأكبر للركام ، ونسبة الماء الى الأسمنت ، ونسبة الرمل إلى الركام ، والنسبة الحجمية للألياف المعدنية ونوعها .

ويهدف هذا البحث إلى عرض النتائج المستخلصة والمعادلات التى تم التوصل إليها للتنبؤ بمتانة الالتواء ، وبالتالى معاملات المتانة . هذه المعادلات تعتمد على إجهاد العزم الأقصى ، وإجهاد الكسر الأول ، ومضاعفات انحناء الكسر الأول ، ومقاس العينة . وقد، وجد أن هذه المعادلات لا تعتمد على مكونات الخلطة الخرسانية العادية .